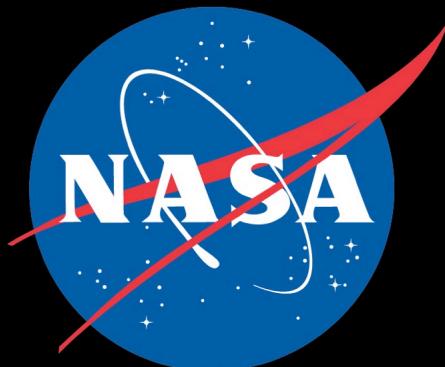


RADAR OBSERVATIONS AND CHARACTERIZATION OF BINARY NEAR- EARTH ASTEROID (35107) 1991 VH, A FLYBY TARGET FOR THE PROPOSED JANUS MISSION

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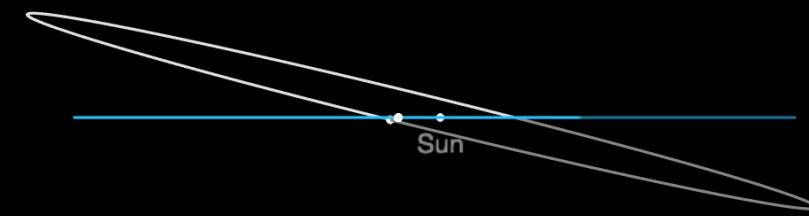
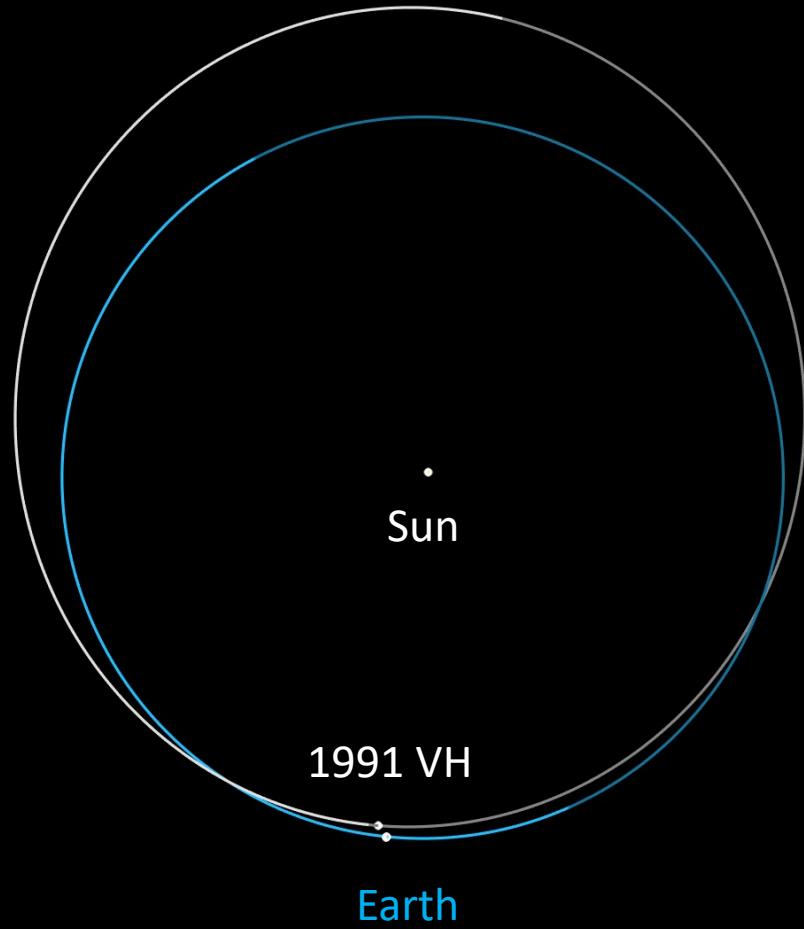
Background

- Discovered by Robert H. McNaught on Nov 9, 1991
- Pravec et al. (1998) discovered its binary nature based on lightcurves from 1997
- Pravec et al. (2006) reanalyzed data obtained in 1997 and also published new observations from 2003
- Arecibo and Goldstone radar observed it in 2008
- Fang & Margot (2012) used radar delay-Doppler measurements to fit mutual orbit parameters
- NEOWISE observed it in Dec. 2013, Jun. 2014, and Jan. 2015 (Nugent et al. 2015)

Summary of Properties

Parameter	Value	Reference
Absolute magnitude	17.02 ± 0.07 & 16.95	Pravec et al. (2006)
	16.8	Nugent et al. (2015)
Diameter	0.91 ± 0.03	Nugent et al. (2015)
	1.1 ± 0.28	
Primary spin period	2.6236 ± 0.0001 h	Pravec et al. (2006)
Mutual orbit period	32.67 ± 0.03 h	Pravec et al. (2006)
Secondary-primary diameter ratio	0.4 ± 0.02	Pravec et al. (2006)
Mutual orbit semimajor axis – primary diameter ratio	2.7 ± 0.3	Pravec et al. (2006)
System mass	1.48e12	Fang & Margot (2012)
Semimajor axis	3.26 ± 0.04 km	Fang & Margot (2012)
Mutual orbit eccentricity	0.05 ± 0.01	Pravec et al. (2006)
	0.06 ± 0.02	Fang & Margot (2012)
Spectral type	Sk	Binzel et al. (2004)
Mutual orbit pole	$(330^\circ \pm 50^\circ, 75^\circ \pm 8^\circ)$ $(180^\circ \pm 30^\circ, -58^\circ \pm 9^\circ)$	Pravec et al. (2006)

Orbit and Close Approach

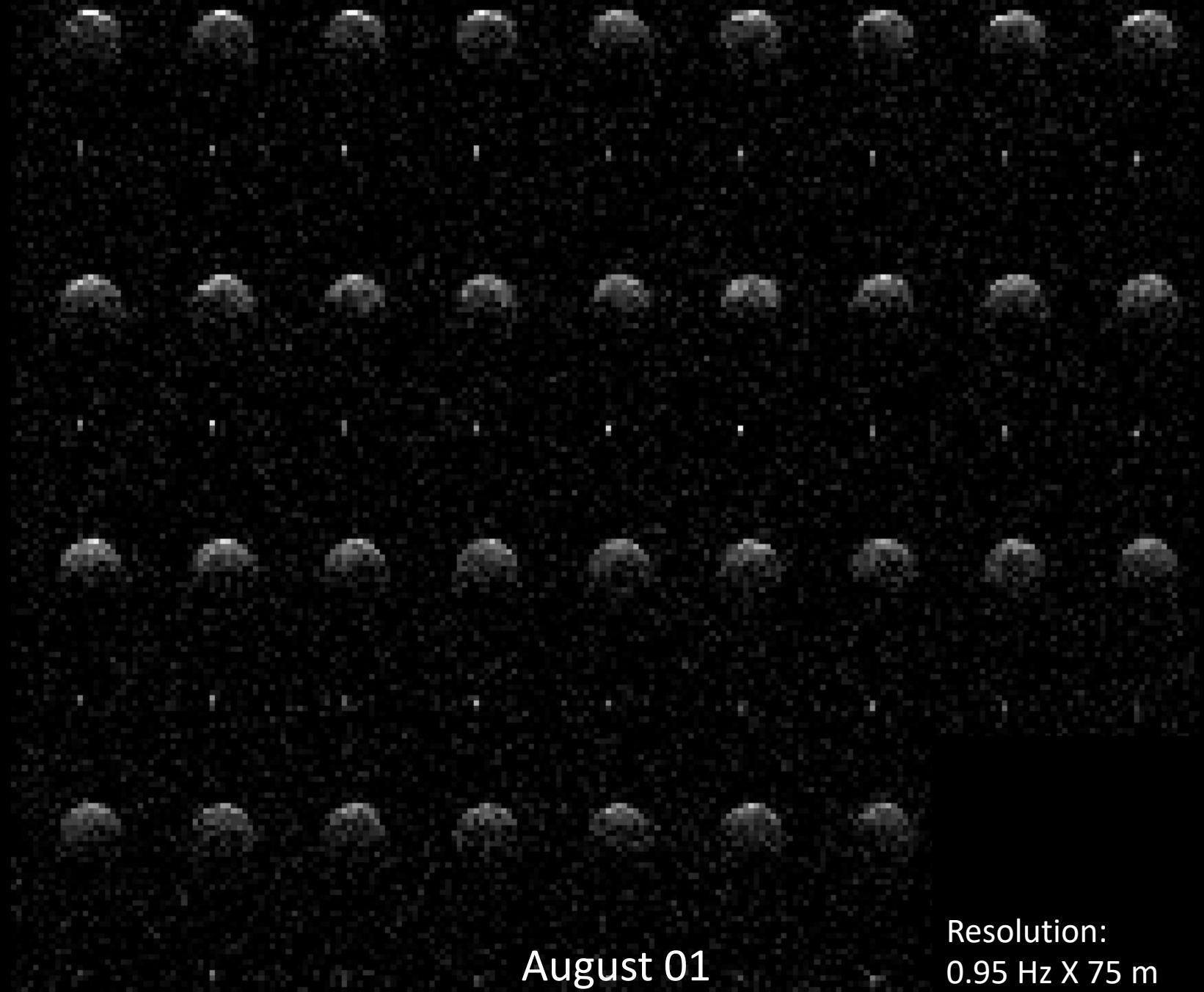


Perihelion distance	0.973 au
Eccentricity	0.144
Inclination	13.9 degrees
Earth MOID	0.26 au
2008 approach	0.045 au
2025 approach	0.078 au

2008 Arecibo Observations

Date	Dec. (degrees)	Round-trip light-time (s)	Imaging Range Resolution	Runs
July 29	38	86	0.1	7
Aug 01	34	76	0.5	34
Aug 05	26	63	0.2 (2 samples/baud)	14
Aug 07	21	57	0.2 (2 samples/baud)	48
Aug 09	15	52	0.2 (2 samples/baud)/0.1	36/4
Aug 10	12	50	0.2 /0.1	15/36
Aug 11	8	49	0.1	48
Aug 12	3	47	0.1	15

Arecibo Images of the Primary



August 01

Resolution:
0.95 Hz X 75 m



August 5

Resolution: 0.3 Hz X 15 m

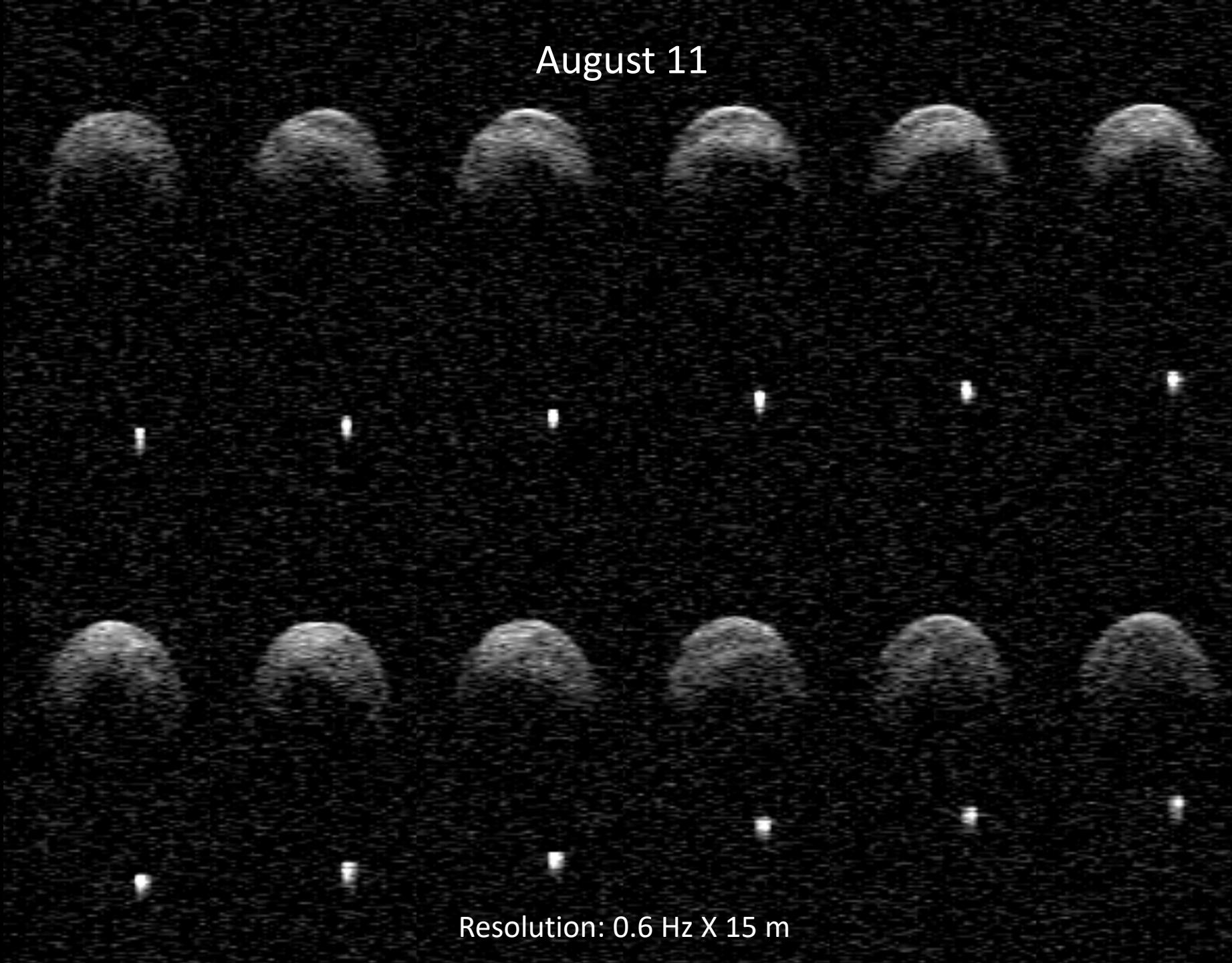
August 7

Resolution: 0.3 Hz X 15 m

August 9

Resolution: 0.3 Hz X 15 m

August 11



Resolution: 0.6 Hz X 15 m

August 12



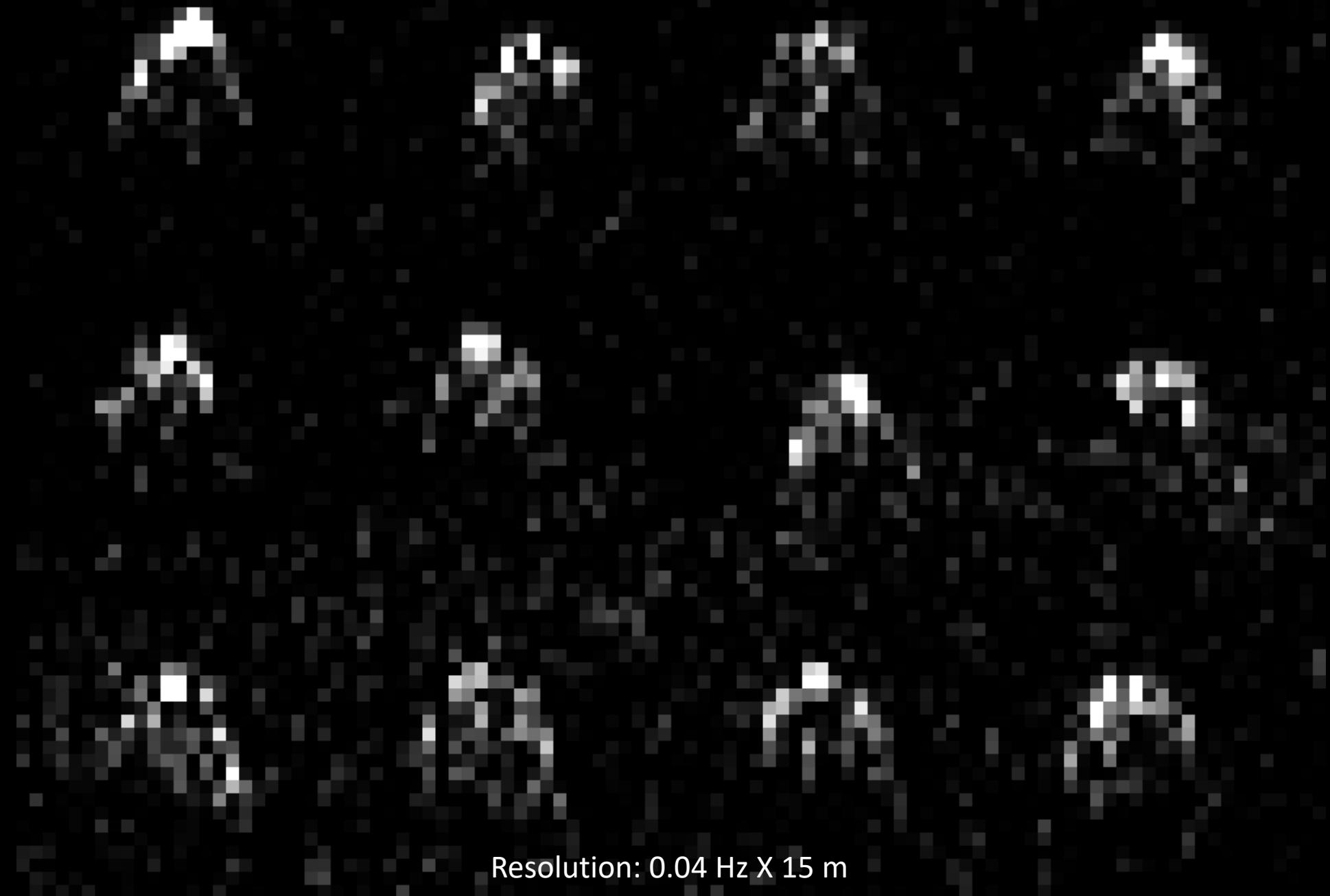
Resolution: 0.6 Hz X 15 m

Arecibo Images of the Satellite

August 7

Resolution: 0.04 Hz X 15 m

August 9

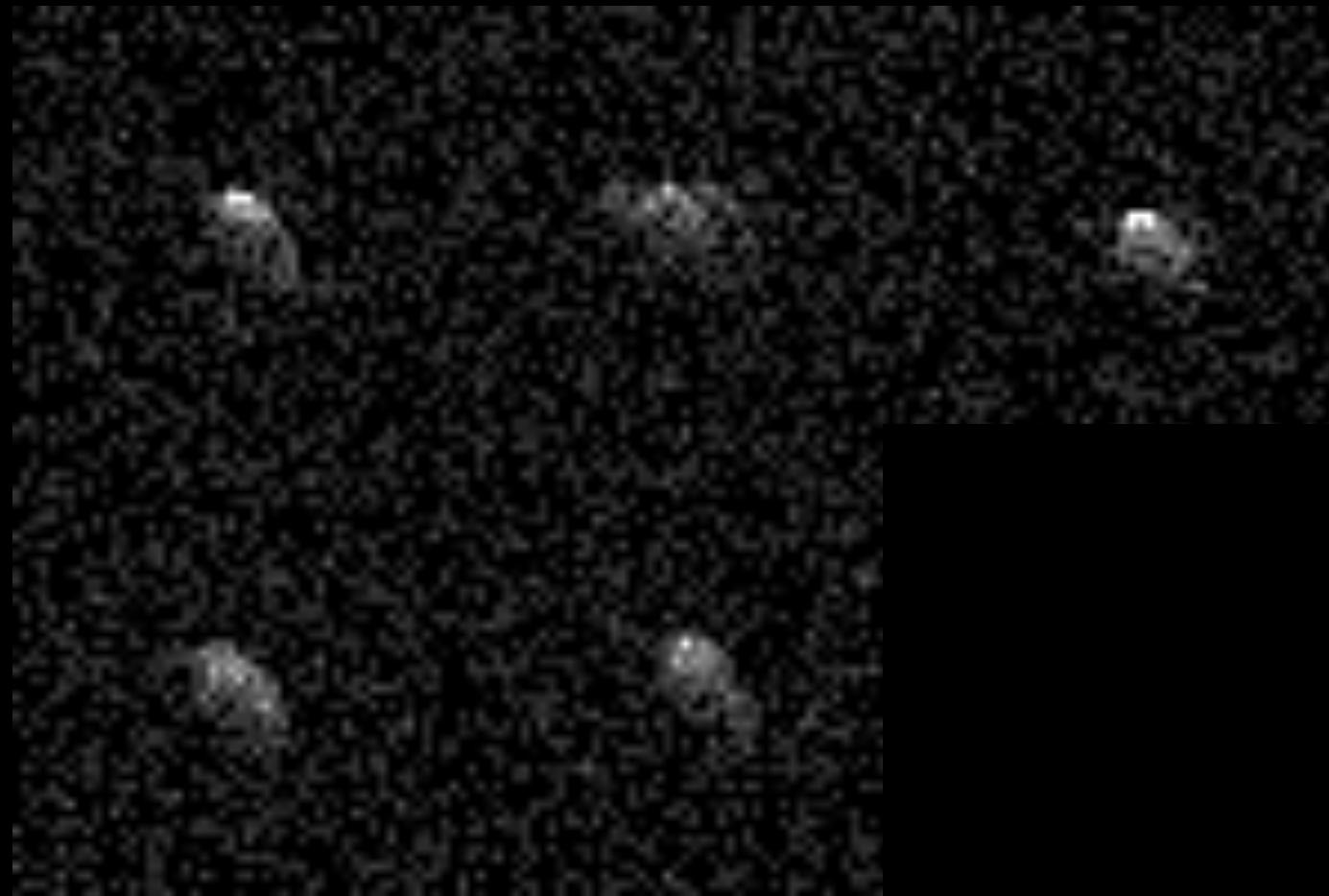


Resolution: 0.04 Hz X 15 m

August 11

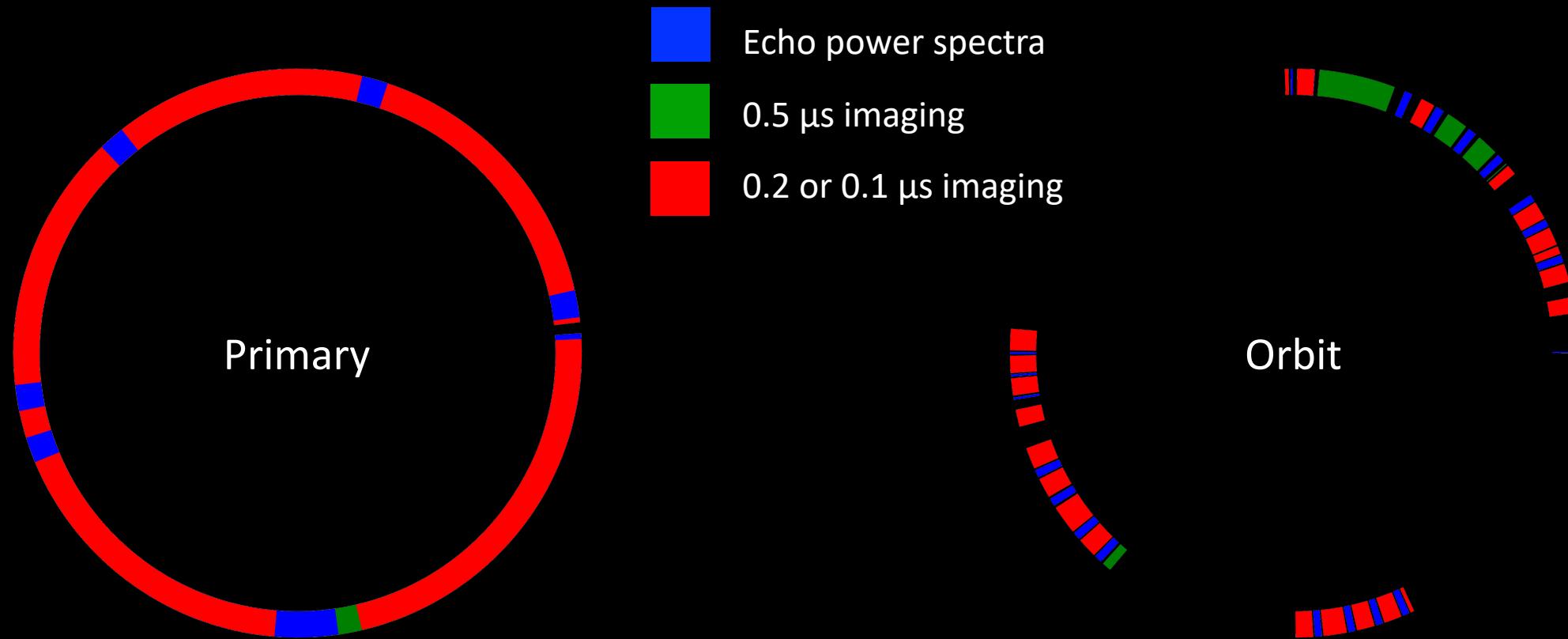
Resolution: 0.02 Hz X 15 m

August 12



Resolution: 0.02 Hz X 15 m

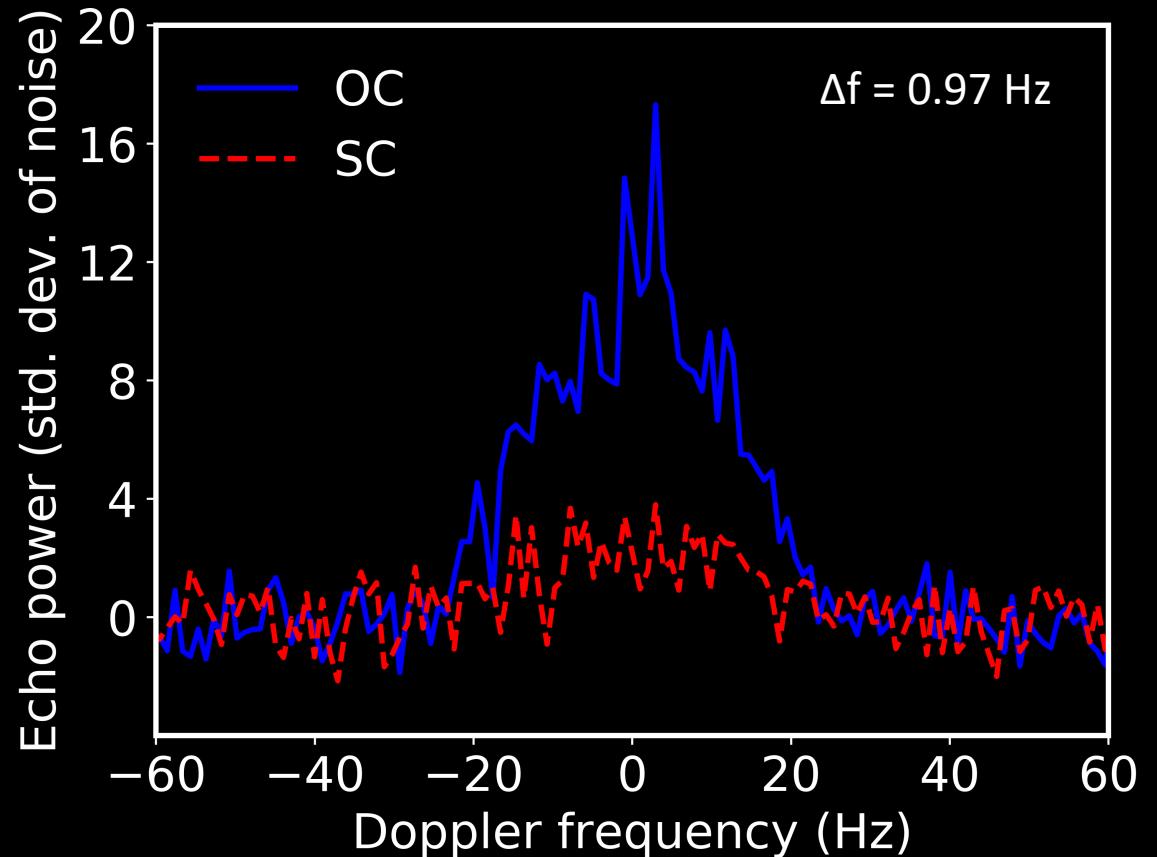
Rotational and Orbital Phase Coverage



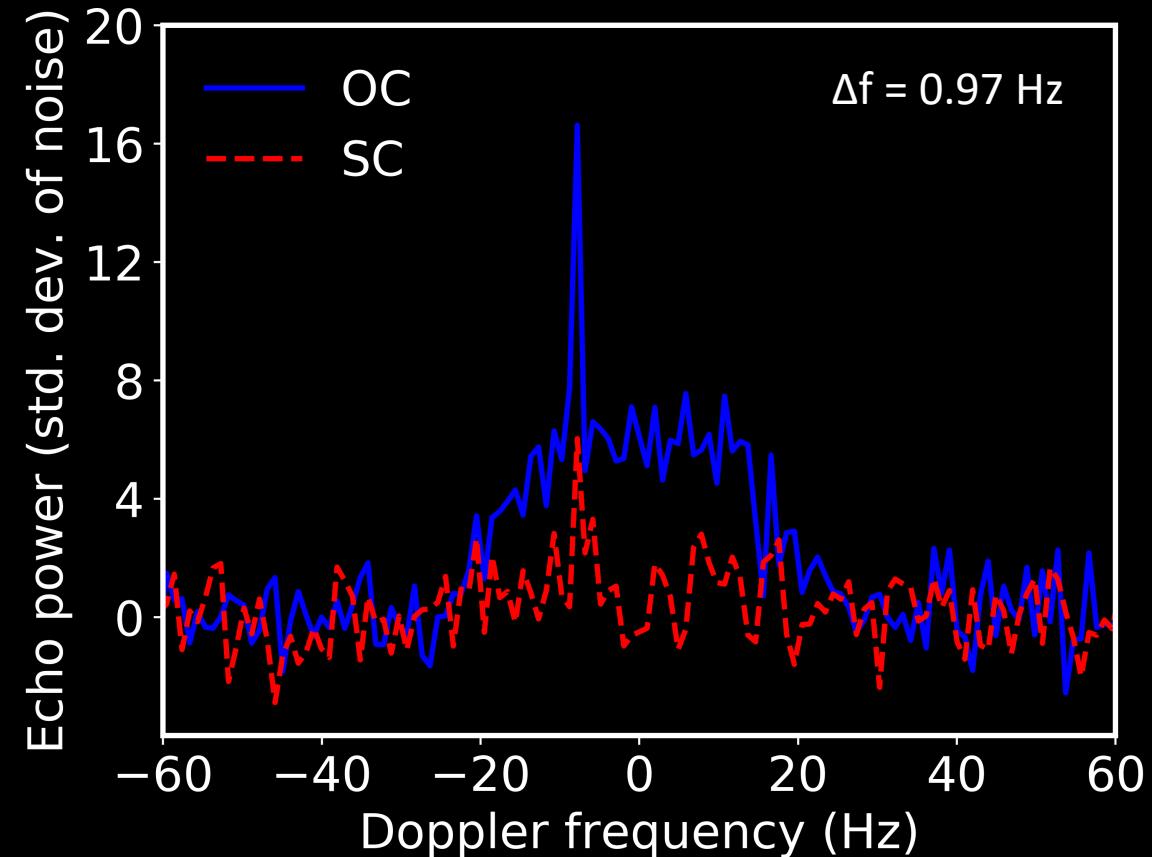
Goldstone Observations

Date	Round-trip light-time (s)	Type of observations	Runs
Aug 06	60	CW	41
	60	1 μs ranging	10
Aug 07	57	CW	20

Goldstone Data

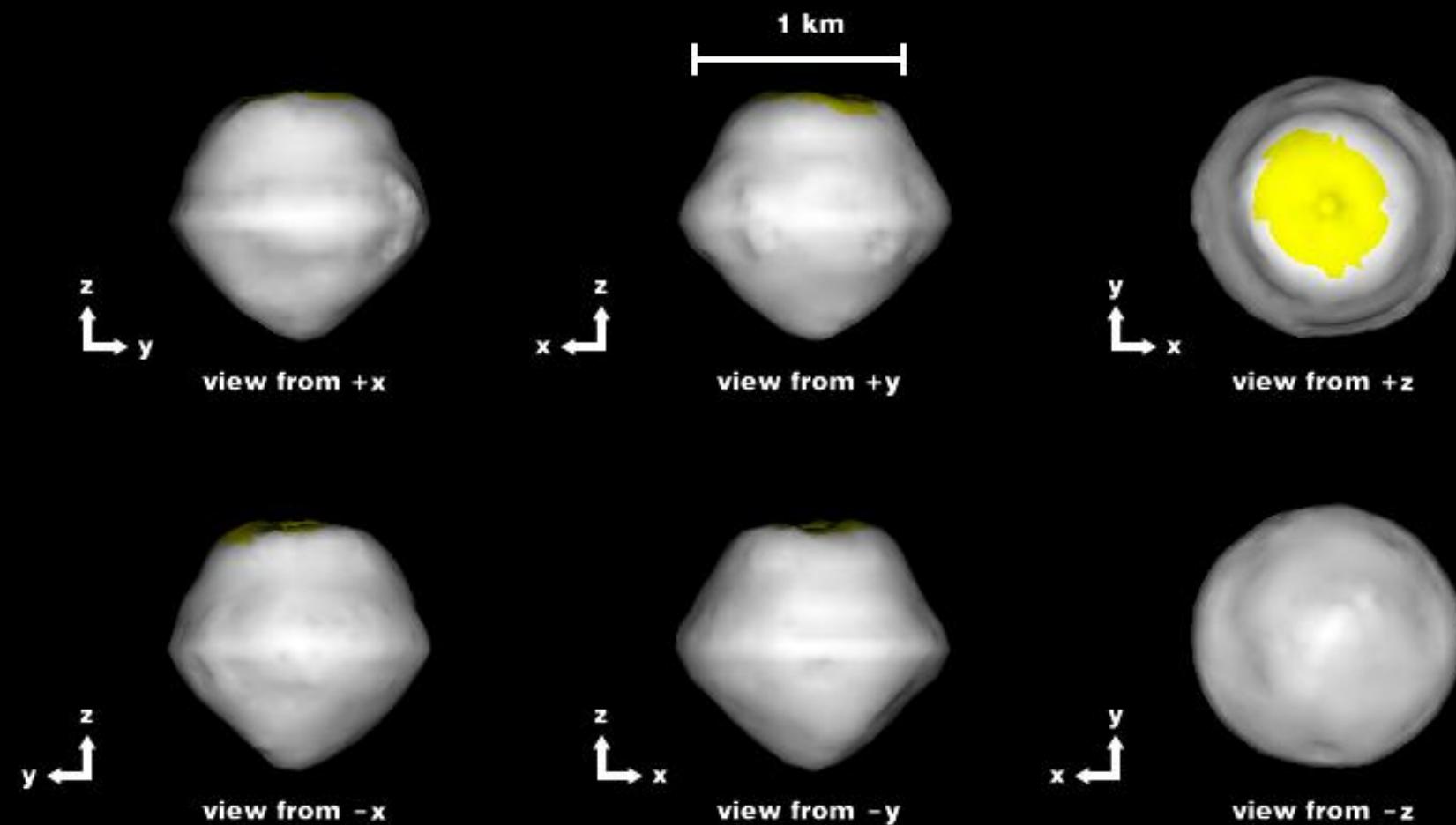


August 6



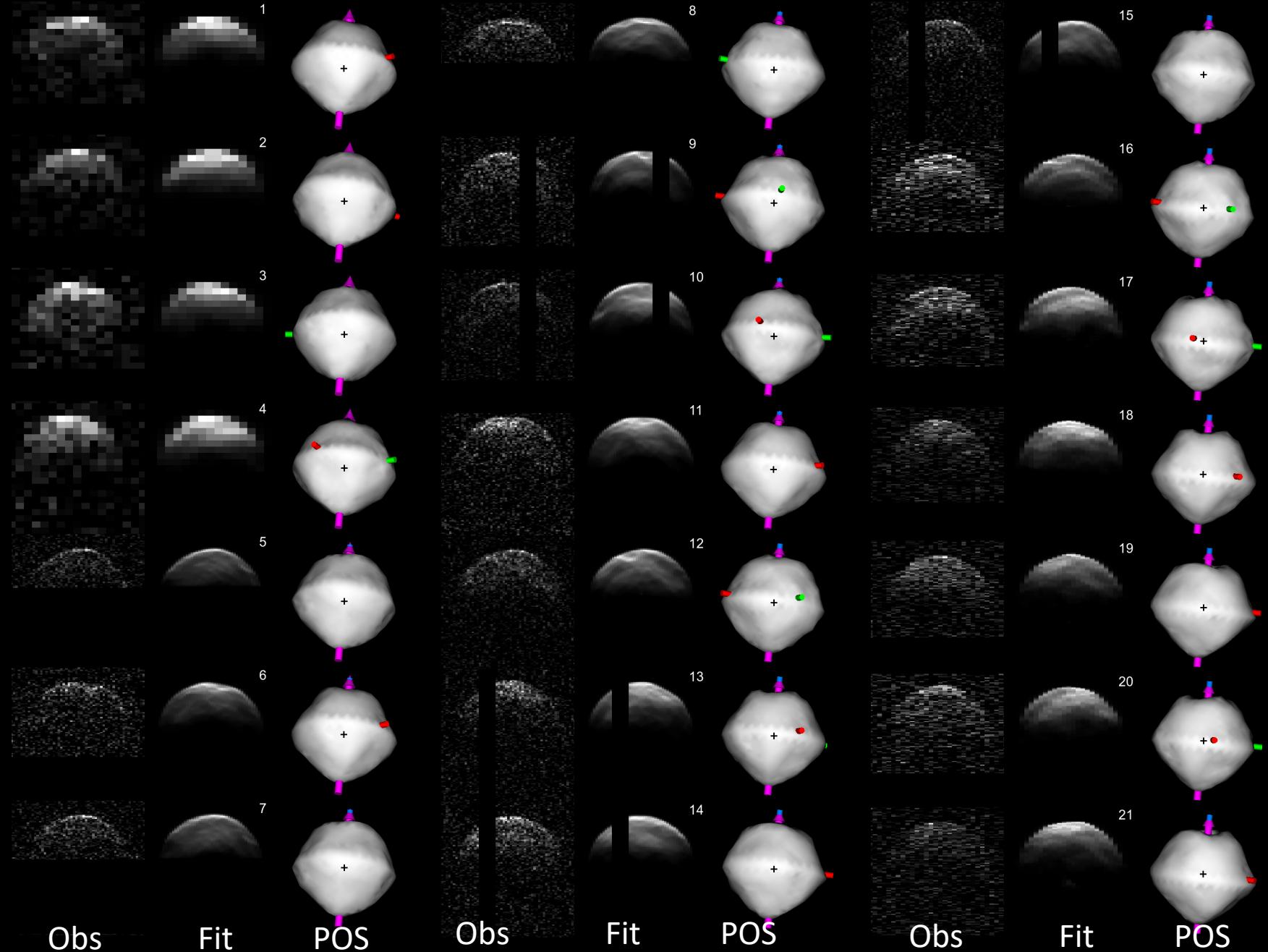
August 7

Preliminary Primary Shape



Primary extents	1.30 x 1.25 x 1.18 km
Volume equivalent diameter	1.18 km
Albedo	0.17-0.18
Model resolution	~100 m

Fits

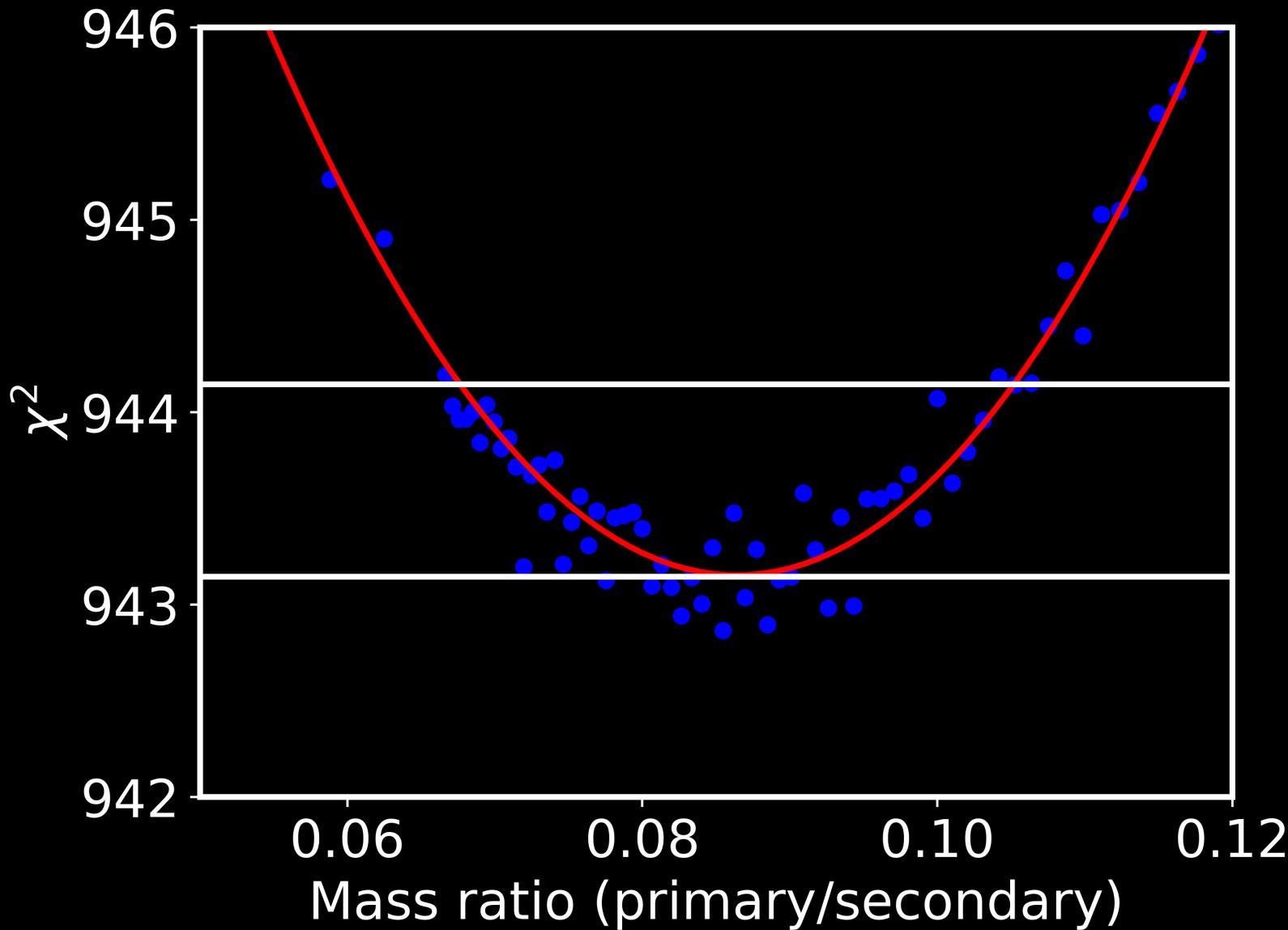


Mutual Orbit

Parameter	Value
System mass	1.58e12 kg +/- 5%
GM_{sys}	105 +/- 5%
Primary density	1700 kg/m ³ +/- 45%
Orbital period	32.57 +/- 0.3 h
Orbit semimajor axis	3.32 +/- 0.07 km
Orbital eccentricity	0.05 +/- 0.01

No clear best-fit orbit pole

Mass Ratio



Summary of System Parameters

Parameter	Value from this work	Pravec et al. (2006)
Primary equiv. diam.	1.18 km ± 15%	--
System mass	1.58e12 kg ± 5%	--
Mass ratio (secondary/primary)	0.086 ± 0.018	--
Primary density	1700 kg/m ³ ± 45%	--
Satellite elongation	> 1.3	--
Primary spin period	--	2.624 ± 0.0001 h
Satellite spin period	--	12.836 (?)
Orbital period	32.57 ± 0.3 h	32.67 ± 0.03 h
Orbit semimajor axis	3.32 ± 0.07 km	Consistent with a/D_p
Orbital eccentricity	0.05 ± 0.01	0.05 ± 0.01
Primary extents (x, y, z)	1.30 x 1.25 x 1.18 km	